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ADDENDUM TO TECHNICAL NOTE R-70

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ABSTRACT

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This Technical Note describes an addition to Technical Note R-70 by the authors. It includes the calculation of the initial liquid levels in the tanks and a variable position interconnect line.

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INTRODUCTION

ABST

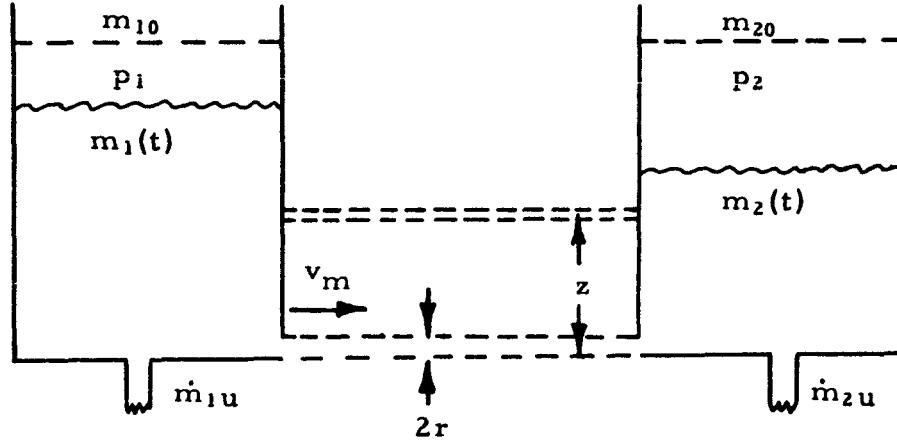
This report describes additions to the FORTRAN program to calculate the relative liquid levels in two interconnected tanks with different flow rates. The original program is discussed in detail in Brown Engineering Company Technical Note R-70. There are two additions to the program. One provides for the calculation of the initial liquid level when given the initial mass, and the other allows for positioning the interconnect line above the tank bottoms.

AUT-HON

THE FORTRAN PROGRAM

Six sets of nonlinear differential equations describe the liquid level in various parts of two interconnected tanks. These equations are solved by a modified Runge-Kutta numerical integration process described in Subroutine RUNGKT and are listed under Subroutine DERIV. Subroutine PRINT is used as the output medium for the solution of the equations at various times.

The physical arrangement of the two tanks is illustrated below.



The two tanks normally consist of a cylindrical center section with an oblate hemispheroid at the top and bottom and are identical, but by input specification either the cylindrical section or the oblate hemispheroids may be discarded and the interconnecting line may be positioned on the tanks or discarded entirely.

If the initial value of the liquid level is read in as -1, the initial heights are calculated using the following equations for different sections of the tanks.

$h > k$

$$h^3 - 3Kh^2 + (3K^2 - 3b^2)h - K^3 + b^3 + \frac{3b^2 m}{2\pi\rho R^2 g_e} = 0$$

$b \leq h \leq K$

$$h = \frac{b}{3} + \frac{m}{2\pi R^2 \rho g_e}$$

$h < b$

$$h^3 - 3bh^2 + \frac{3b^2 m}{2\pi R^2 \rho g_e} = 0$$

where

b - minor semi-axis of the oblate hemispheroid part of the tank

g_e - gravitational constant on the earth

$h = h_{10} = h_{20}$

K - length of the cylindrical part of the tank + b

m - total initial mass of liquid in the tanks

R - radius of the tank

ρ - mass density of the liquid

The program was written primarily for the normal vehicle flight process; however, it can also be used for certain special cases, namely,

non-flight operation, emergency draining, and filling when the following provisions are observed.

A. IN-FLIGHT DRAIN

1. $\dot{\omega}_{2u}$ must be greater than $\dot{\omega}_{1u}$ in order to keep h_1 greater than h_2 .
2. Any values can be provided for p_e and r_e .
3. p_1 must be equal to or greater than p_2 .

B. NON-FLIGHT OPERATION

1. Set $F = W_o = 1$ and $\dot{\omega}_p = 0$ to eliminate the effects of flight.
2. $\dot{\omega}_{2u}$ must be greater than $\dot{\omega}_{1u}$ as in A1 above.
3. Any values can be provided for p_e and r_e .
4. p_1 must be equal to or greater than p_2 .

C. EMERGENCY DRAIN

1. Set $\dot{\omega}_{1u} = \dot{\omega}_{2u} = 0$ as a signal for an emergency drain.
2. Set $F = W_o = 1$ and $\dot{\omega}_p = 0$ as in B1 above.
3. p_2 must be greater than or equal to p_e .

D. FILLING

1. $\dot{\omega}_{1u}$ is made negative and $\dot{\omega}_{2u}$ is set equal to zero in order to fill tank 1.
2. $F = W_o = 1$ and $\dot{\omega}_p = 0$ as in B1 above.
3. h_{10} is set equal to zero in order to fill the tanks.

ADDENDUM TO SUBROUTINE RUNGKT

When $y_1 < Z$, F_{173} is set to zero.

ADDENDUM TO THE LIST OF FORTRAN SYMBOLS

$F_{175} = Z - \text{distance from the bottom of the tanks to the center of the interconnect line.}$

ADDENDUM TO THE INPUTS

Card #5, h_{10} , r, q

Fill tanks if $h_{10} = 0$.

Calculate h_{10} if $h_{10} = -1$.

Use input value of h_{10} if positive.

Card #7, Code, Z

Where Z is the distance from the bottom of the tanks to the center of the interconnect line in inches.

FORTRAN IV PROGRAM LISTING OF CONTROL PROGRAM SP 72

```
DIMENSION Y(25),DY(25),F(175)

COMMON Y,DY,F,P,TT,TP,TE,E2,I,NCI,NN,T

2 READ (5,1)          (F(M),M=160,174) ,F(140),F(142),F(143),
1CODE,F(175)

F(156) = 386.088 * F(163)* 3.1415927 * F(162)**2

1 FORMAT(3E13.6)

F(141) = F(160) +F(161)

F(146) = 386.088 *F(163)*3.1415927

KKKK = 4

F(148) = (F(173)/F(142))**KKKK

F(147) = (F(162)/F(142))**KKKK - 1.

F(150) = F(146)/F(147)

NCI = 0

NN = 2

P = .5

TP = 5.

E2 = .000005

T = 0.

TT = 0.

I = 4

TE = F(171)

H = F(172)

IF(F(172).GT.0) GO TO 9

H = F(161)/3. + F(140)/(2.*F(156))

IF(F(172).EQ.0.) GO TO 8
```

FORTRAN IV PROGRAM LISTING OF CONTROL PROGRAM SP 72

```
XX = 3.*F(161)**2*F(140)/(2.*F(156))

IF(H.GT.F(160)) GO TO 4

IF(H.GE.F(161)) GO TO 9

H = F(161)

3 X =(H**2*(H-3.*F(161)) + XX )/( 3.*F(161)**2)

IF(ABS(X).LT.F(161)/1.E+08) GO TO 9

H = H + X

GO TO 3

4 XXX = XX - F(160)**3 + F(161)**3

XY = 3.*(F(160)**2 - F(161)**2)

H = F(160)

5 X =((H - 3.*F(160))*H + XY)* H + XXX)/(3.*F(161)**2)

IF(ABS(X).LT.(F(160)+F(161))/1.E+08) GO TO 9

H = H + X

GO TO 5

8 H = .01

9 Y(1) = H

Y(2) = Y(1)

F(154) = 1.

F(155) = 50.

WRITE (6,6) T,TE

WRITE(6,7)      (F(M),M=160,162),F(173),H      ,(F(M),M=163,170)

1,F(174),(F(IX),IX = 140,143) ,F(175)

6 FORMAT(1H1,                                20X,94HAN ANALYSIS OF THE RELATIV
1E LIQUID LEVELS IN TWO PROPELLANT TANKS WITH AN INTERCONNECTING LI
```

FORTRAN IV PROGRAM LISTING OF CONTROL PROGRAM SP 72

```
2NE/////19X, 11HTIME IS NOWF10.2,3HSEC37X, 24HTHE LENTH OF THIS RU  
3N ISF10.2,3HSEC//////////)  
7 FORMAT(1H ,19X,3HK =E15.8,42X,3HB =,E15.8//20X,20HRADIUS OF THE TA  
1NK =E15.8,25X,20HRADIUS OF THE LINE =E15.8//20X,18HHEIGHT OF LIQUI  
2D =E15.8, 27X,5HRHO =E15.8//20X ,14HFLOW RATE 1U =E15.8,31X,14H  
3FLOW RATE 2U =E15.8//20X,8HTHRUST =E15.8,37X,4HWO =E15.8//20X,  
4 22HPROPELLANT FLOW RATE =E15.8,23X,4HP1 =E15.8//20X,4HP2 =E15.8,  
541X,3HQ =E15.8//20X,37HTOTAL MASS OF PROPELLANT IN THE TANKSE13.6,  
610X,17HHEIGHT OF TANK 1.E13.6//20X,21HRADIUS OF THE DRAIN =E13.6  
7,26X,4HPE =E13.6/20X,3HZ =E15.8)  
IF(F(164).EQ.0.)  TP = 1.  
F(51) = 1.  
CALL RUNGKT  
CALL PRINT  
IF (CODE.EQ.0.) GO TO 2  
WRITE (6,102)  
102 FORMAT(1H1/////////25X,10HEND OF JOB//1H1)  
CALL EXIT  
END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PRINT

SUBROUTINE PRINT

DIMENSION Y(25),DY(25),F(175)

COMMON Y,DY,F,P,TT,TP,TE,E2,I,NCI,NN,T

IF(F(155) -22.) 60,61,61

61 F(155) = 0.

KP = F(154)

F(154) = F(154) + 1 .

WRITE (6,62) KP

62 FORMAT(1H1,50X,14HPROGRAM OUTPUT//110X,8HPAGE NO.14///,8X,1HT8X,
1 2HH115X, 2HH213X, 5HH1-H28X, 12HWEIGHT DIFF.4X,12HACCELERATION
2,4X,13HLINE VELOCITY6X,3HW2U///)

60 F(155) = F(155)+1.

A1 = F(156)

NK1 = 1

NK2 = 1

WL1 = 0.

Y1 = Y(1)

Y2 = Y(2)

XH12 = Y1 - Y2

WL = 0.

IF(Y2 - F(160)) 1,1,2

1 IF(Y2 - F(161)) 11,30,30

11 IF(Y1 - F(161)) 3,31,31

30 IF(Y1 - F(160)) 4,4,6

31 IF(Y1 - F(160)) 12,12,32

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PRINT

```
32 NK2 = 2
  6 NK1 = 4
    XH12 = Y(1) - F(160)
    Y2 = F(160)
    GO TO 2
12 NK1 = 2
    Y1 = F(161)
    XH12 = Y(1) - F(161)
    GO TO 3
16 GO TO (18,17),NK2
17 WLL = WL
    Y2 = Y(2)
    NK1 = 2
    Y1 = F(161)
    XH12 = F(160) - F(161)
    GO TO 3
18 XH12 = F(160) - Y(2)
  9 NK1 = 3
    WLL = WL + WLL
    GO TO 4
2 WW6=3.*F(161)**2
    WW10 = Y1 - F(160)
    WW3=XH12-WW10*WW10*WW10 /WW6
    WW9 = Y2 - F(160)
    WW5 = WW9*WW9*WW9
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PRINT

```
WW4=WW5/(3.*F(161)**2)
WL = A1 • ( WW3 + WW4 )
GO TO 5
3 WW1 =(Y1**2 - Y2**2) /F(161)
WW2 = (Y1 *Y1 * Y1-Y2 • Y2 • Y2 )/ (3.*F(161)**2)
WL = A1 • (WW1 -WW2 )
GO TO 5
4 WL = A1* XH12
5 GO TO ( 7,9,13,16),NK1
13 WL = WL + WLL
7 XH12 = Y(1)-Y(2)
      WRITE (6,8) T,      Y(1),Y(2),XH12,WL, F(144),F(145),F(149)
8 FORMAT(1H0,F10.2,7E16.6 )
14 RETURN
END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE DERIV

SUBROUTINE DERIV

```
DIMENSION Y(25),DY(25),F(175)

COMMON Y,DY,F,P,TT,TP,TE,E2,I,NCI,NN,T

A4 =2.*Y(1)/B - (Y(1)/B)**2

A5 =2.*Y(2)/B - (Y(2)/B)**2

A3 = F(156)

XK = F(160)

B = F(161)

ALF = F(168)/F(167)

GT = F(166)*386.088 / (F(167)*(1.-T*ALF))

F(144) = GT

XH12 = Y(1) - Y(2)

IF( XH12 ) 11,12,12

11 XH12 = -XH12

12 A1 = 1.-(Y(1)- XK)**2/B**2

      A2 = 1.-(Y(2)- XK)**2/B**2

      VMA = ( 2.*GT * XH12 + 2.*(F(169)-F(170))/F(163))/F(174)

      F(145) = SQRT(VMA)

      VM = SQRT (VMA) *(F(173)/F(162))**2*2.

      IF(F(164))14,15,14

14 F(149) = F(165)

      GO TO 16

15 B4 = 772.176 * Y(2) + (F(170) - F(143))/F(163)

      B5 = B4 * F(147)

      B3 =      F(148)*VMA + B5
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE DERIV

```
B2 = SQRT(B3)

F(149) = F(150)      *(F(162)**2*B2 - F(173)**2*F(145))

16 IF(Y(1)- XK ) 1,1,2
1 IF(Y(1)- B )4,3,3
2 CONTINUE

DY(1) = (- F(164)*2./A3-VM)/(2.*A1)
GO TO 5

4 DY(1) = (- F(164)*2. / A3 - VM) / (2.*A4)
GO TO 5

3 DY(1) = - F(164)      / A3 - VM/2.
CONTINUE

5 IF( Y(2) - B) 17, 6, 6
6 IF( Y(2) - XK) 18,18,7
17 IF( Y(1) - XK)20,20,19
18 IF( Y(1) - XK) 8,8,22
19 DY(2) =(-DY(1)* A1 -(F (149)+F(164))/A3)/A5
GO TO 10

20 IF(Y(1) - B) 9,21,21
21 DY(2) =(-DY(1)      -(F (149)+F(164))/A3)/A5
GO TO 10

22 DY(2) =-DY(1)*A1-(F(149)+F(164))/A3
GO TO 10

7 DY(2) = (-DY(1)*A1 -(F(149)+F(164))/A3)/A2
GO TO 10

8 DY(2) = -DY(1) - (F(149)+F(164))/A3
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE DERIV

```
GO TO 10  
9 DY(2) =(-DY(1)* A4 -(F (149)+F(164))/A3)/A5  
10 CONTINUE  
RETURN  
END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

SUBROUTINE RUNGKT

C PREPARED BY BEN H KAVANAUGH JR

DIMENSION Y(25),DY(25),F(175)

COMMON Y,DY,F,P,TT,TP,TE,E2,I,NCI,NN,T

E1 = E2/100.

NCII = 0

N = NN

L = 4

DI = TP

TP = DI + TT

800 T = TT

GO TO (75,200,300,400),L

75 IG = IG

GO TO (101,102),IG

101 J = 1

L = 2

M = 0

TS = T

DO 106 K = 1,N

K1 = K + N * 3

K2 = K1 + N

K3 = N + K

F(K1) = Y(K)

F(K3) = F(K1)

106 F(K2) = DY(K)

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
GO TO 402
102 GO TO 60
99 J = J + 1
IF(J-I) 103,103,104
103 L = 1
GO TO 402
104 M = M + 1
105 GO TO (110,120,130),M
110 DO 111 K = 1,N
K1 = K + N + N
111 F(K1) = Y(K)
112 DO 113 K = 1,N
K1 = K + 3*N
K2 = K1 + N
K3 = N + K
Y(K) = F(K1)
F(K3)= F(K1)
113 DY(K) = F(K2)
T = TS
IF(P) 114,116,114
114 IF (ABS (H/P)-.0000005) 115,115,116
115 M = 0
L = 4
GO TO 402
116 DT = .5*H
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
M = 1
J = 1
GO TO 300
120 DO 121 K = 1,N
      K1 = K + N
121 F(K1) = Y(K)
      M = 2
      J = 1
      IG = 2
      L = 1
      GO TO 402
130 DO 131 K = 1,N
      K1 = K + 2*N
      F(K) = (Y(K)-F(K1))/(2.***I-1.)
      Y(K) = Y(K) + F(K)
      IF(ABS(F(K))-0.00001)139,139,140
139 F(K)= 0.
      GO TO 131
140 F(K) = ABS (F(K)/Y(K))
131 CONTINUE
      E = F(1)
      INDEX = 1
      IF (N-1)1335,1335,1315
1315 DO 133 K = 2,N
      IF(E-F(K))132,133,133
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
132 INDEX = K  
      E = F(K)  
133 CONTINUE  
1335 IF(E-E1)134,135,135  
134 H = H + H  
1345 DT = H  
      GO TO 401  
135 IF(E-E2)1345,1345,136  
136 DO 137 K = 1,N  
      K1 = K + N  
      K2 = K + N + N  
137 F(K2) = F(K1)  
138 H = .5*H  
      GO TO 112  
200 MU = MU  
      GO TO (203,204),MU  
203 H=AMAX1(H,H1,H2)  
      MU = 2  
204 H1 = ABS (H)  
      IF(P)205,206,206  
205 H = -H1  
      GO TO 207  
206 H = H1  
207 IF(ABS (P)-H1)208,209,209  
208 H = P
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
209 T2 = TP - T
      IF(T2)210,212,210
210 H2 = ABS (T2)
      IF(ABS(TP) -5.E-08)212,211,211
211 IF(ABS (T2/TP)-.00001) 212,213,213
212 T = TP
      L = 3
      GO TO 402
213 M = 0
      J = 1
      IF(H1-H2) 215,215,214
214 MU = 1
      H = T2
215 DT = H
300 IG = 2
      GO TO 102
400 MU = 2
      H = P
      DT = P
      N = NN
401 IG = 1
      L = 1
402 TT = T
      GO TO ( 902,903,904,905 ),L
903 IF(F(140) - T*ABS(F(164))) 1101,1101, 1102
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
1103 IF( Y(1) - F(141))1104,1101,1101
1102 IF( Y(1)) 1101,1103,1103
1101 RETURN
1104 IF(Y(1).GE.F(175)) GO TO 800
      IF(F(51).EQ.0.) GO TO 800
      F(51) = 0.
      PER = (F(169) + F(170))/ 2.
      F(169) = PER
      F(170) = PER
      F(173) = 0.
      GO TO 800
904 CONTINUE
      CALL PRINT
      IF(ABS(TP-TE)-.2E-07)901,901,801
801 TP = TP + DI
      GO TO 800
905 WRITE(6,909)INDEX,TT,Y(INDEX)
909 FORMAT(1HO,///5X,I2,25HDOES NOT CONVERGE AT T = ,F14.8,25HCURRENT
      1VALUE OF Y(I) IS ,E15.8///)
      IF(NCI-NCII)901,901,908
908 NCII = NCII + 1
      J = 1
      IG = 1
      DT = H
      M = 0
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
GO TO 800

60 DO 100 K = 1,N
      K1=K
      K2=K+5*N
      K3=K2+N
      K4=K+N
      GOTO (999,85,95,95),I
85 GOTO (86,2,999,999),J
86 F(K1)=DY(K)*DT
      Y(K)=F(K4)+F(K1)
      GO TO 100
95 GOTO (1,2,3,4),J
1   F(K1)=DY(K)*DT
      Y(K)=F(K4)+.5*F(K1)
      GO TO 100
2   F(K2)=DY(K)*DT
      GOTO (999,22,23,24),I
3   F(K3)=DY(K)*DT
      GOTO (999,33,33,34),I
4   Y(K)=F(K4)+(F(K1)+2.*(F(K2)+F(K3))+DY(K)*DT)/6.
      GOT0100
22  Y(K)=.5*(F(K1)+F(K2))
      GOT025
23  Y(K)=2.*F(K2)-F(K1)
      GOT025
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE RUNGKT

```
24 Y(K)=.5*F(K2)
25 Y(K)=Y(K)+F(K4)
      GOT0100
33 Y(K)=F(K4)+(F(K1)+4.*F(K2)+F(K3))/6.
      GOT0100
34 Y(K)=F(K4)+F(K3)
100 CONTINUE
      GO TO (50,61,62,58),J
50 GO TO (999,56,57,57),I
61 GO TO (999,58,57,58),I
62 GO TO (999,58,58,57),I
56 T = DT + T
      GO TO 58
57 T = T + .5* DT
58 GO TO 99
999 CALL DUMP
902 CONTINUE
      CALL DERIV
      GO TO 800
901 RETURN
      END
```